EURAMET project No. 1308
Pilot study

Comparison of air speed facilities using LDAs as reference standards

Final Report

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Contents

1 Introduction

A pilot study between the Austrian DI for airspeed and the Swiss NMI METAS has been organised to assess the effect of wind tunnel cross section and calibration methods on the calibration results for two transfer standards with notable different apparent surfaces over a speed range from 0.5 m/s to 40 m/s:

- a Pitot tube with a diameter of 8 mm and
- a vane anemometer with a diameter of 85 mm.

1.1 Participants

The participants in EURAMET 1308 were:

Marc de Huu METAS, pilot marc.dehuu@metas.ch

Mathias Rohm BEV/ E+E until August 2014

Dietmar Pachinger BEV/ E+E starting September 2014 dietmar.pachinger@epluse.at

The comparison measurements started in July 2014 and finished in October 2014. A second round has been performed in the summer of 2015. A final group of measurements took place in the METAS' tow channel in May 2017.

2 Transfer standards (TS)

The transfer standards were a Pitot tube, supplied by BEV/ E+E, and a vane anemometer supplied by METAS. The characteristics were the following:

Manufacturer	Type	Designation	Serial No	Measuring range
Schiltknecht	Pitot Tube	ManoAir 500 (56697)	3212	200 Pa
Schiltknecht	Vane Anemometer	MiniAir20 Macro Readout/Display	C-72268 75792	(0.3 – 40.0) m/s

3 Facilities description

3.1 METAS facilities

Closed-loop wind tunnel with an open rectangular test section 75 cm x 45 cm and a length of 82 cm. The contraction ratio is 4.

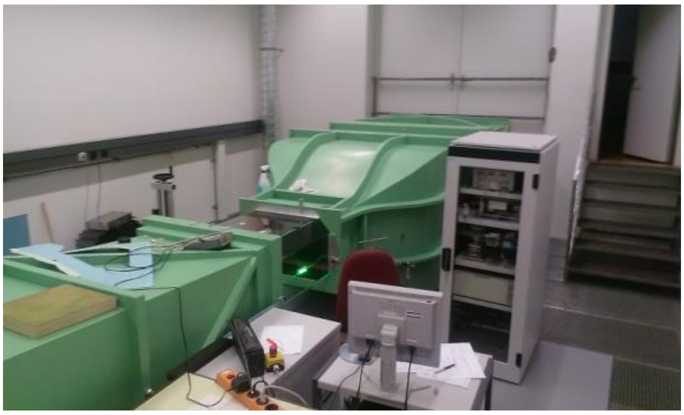


Figure 1: METAS wind tunnel.

Velocity range	(0.1 50) m/s
Uncertainty (k=2)	0.02 m/s for (0.1 … 1.0) m/s
	2% for (1.0 … 13.0) m/s
	3% down to 1% for (13.0 … 50) m/s
Ambient conditions	(19.0 … 25.0) °C
	(920 … 980) hPa
	(40 … 60) %
Reference instruments	Vane anemometer ‘Lambrecht’
	Pitot tube
	LDA: ILA Flowpoint Fp50Shift

Traceability is achieved through the ‘Lambrecht’ vane anemometer, which is calibrated in our tow channel in the range (0.1 … 13) m/s and traceable through length and time. For higher speeds, a Pitot tube is used. Calibration procedures are currently being established with an LDA traceable to PTB. Up to now, no certificates have been issued based on LDA data. Measurement devices for the state variables (pressure, temperature and humidity) are calibrated every 4 years and any deviations are considered.

The tow channel has dimensions 2.4 m x 2.4 m x 52 m and a measuring length of 30 m.

Velocity range	(0.02 … 13) m/s
Uncertainty (k=2)	0.3% + 0.01 m/s
Ambient conditions	(19.0 … 25.0) °C
	(920 … 980) hPa
	(40 … 60) %
Reference instruments	Length and time

3.2 BEV/E+E facility

Göttingen (closed-loop) wind tunnel with an open circular test section of 25.5 cm diameter and a length of 30 cm. The contraction ratio is 4.

Velocity range	(0.3 … 40) m/s
Uncertainty (k=2)	$0.004 m/s + 0.0047 \cdot v$
Temperature range	(5 … 80) °C
Ambient conditions	(19.0 … 25.0) °C
	(920 … 1013) hPa
	(40 … 60) %
Reference instruments	LDA: ILA Flowpoint 550

The Laser Doppler Anemometer (LDA) is calibrated every 3 years at PTB in Braunschweig. The actual calibration of the distance of the interference fringes is used for the determination of the air velocity. Measurement devices for the state variables (pressure, temperature and humidity) are calibrated once a year and any deviations are considered.

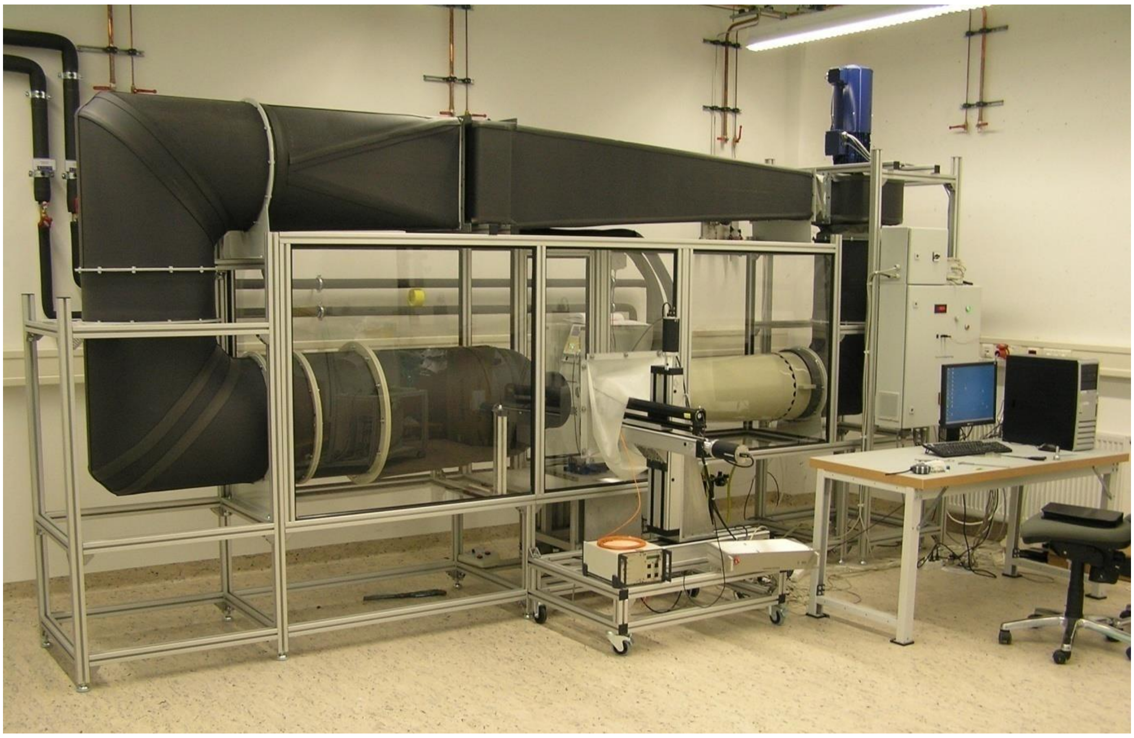
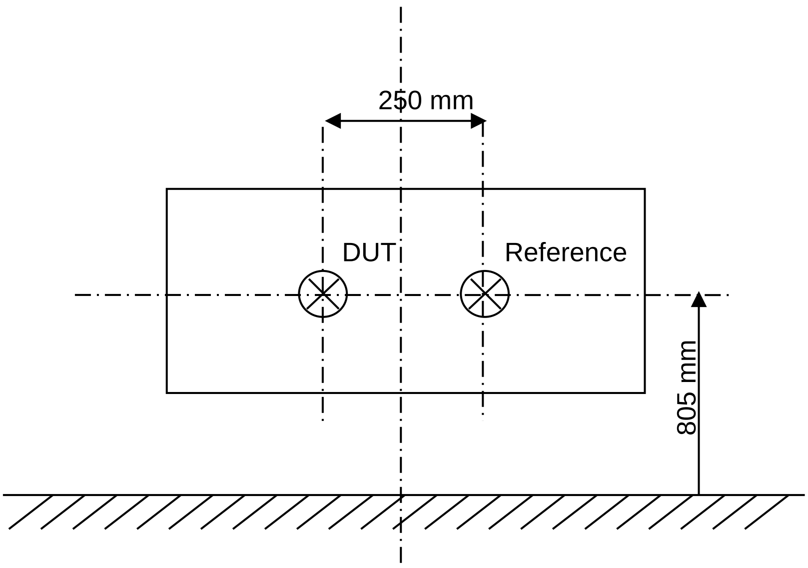


Figure 2: closed loop wind tunnel with an open test section

4 Measurement procedures

4.1 METAS procedures

During the calibration process in the wind tunnel, the Device Under Test (DUT) and the reference instrument are measured at the same time and are placed symmetrically along the axis of the test section in the wind direction. Height with respect to the ground does not play a major role but should be between 655 mm and 805 mm from the ground.



In the tow channel, the anemometer is moved in still air. A rail is mounted below the ceiling of a tunnel 50 m long with a cross-section of 2.4 m to 2.4 m. On this rail a carriage drives with low friction losses. The anemometer is fixed in front of this carriage. The carriage is pushed with controlled force for the first 5 m of its way. For a distance of 10 m, the anemometer can stabilize its revolving speed. The following 30 m are the distance on which the anemometer is calibrated. Every 10 m the carriage actuates an optical switch without touching it mechanically. The speed of the carriage is recorded by recording the time of actuation of the switches. The display of the DUT is read out with a camera.

4.2 BEV/ E+E procedure

A Laser Doppler Anemometer (LDA) is used as reference instrument because it allows the measurement of the air velocity without influencing the flow profile and thus without influencing the air velocity.
During the calibration process, the DUT and the reference (LDA) are measured at the same time. Deviations of the air velocity at the reference position and the calibration position (see Figure 3) have to be considered with the help of a correction factor. Therefore, the air velocity at the reference-position and at the calibration-position is measured with the LDA in the unaffected flow profile. This results in a correction parameter for the reference velocity which depends on the air velocity and thus has to be determined for each velocity separately prior to the calibration.

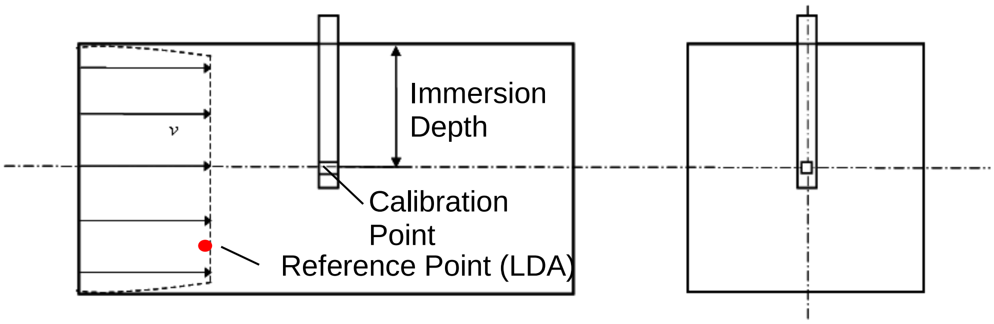


Figure 3: Reference and Calibration Position

Usually a DUT is a body with geometrical dimension that interacts with the flow field within the measurement section. Upstream of the DUT parts of the flow is jammed, usually known as the Blockage Effect (BE). The size of the affected area depends on the dimensions of the DUT.
For every new DUT its influence on the flow profile is determined. Therefore a profile measurement is done with and without the DUT at a certain air velocity. In order to avoid or minimize an influence of the Blockage-Effect to the calibration result the reference position is chosen upstream at a position with no influence of the DUT on the flow profile. If no such position is available, e.g. geometrical dimension of the DUT are too large, the remaining influence is calculated within the uncertainty budget.
Finally, the blockage effect additionally results in an modification of the flow profile along the cross-section due to the law of continuity. It depends on the quotient of geometrical dimension of the DUT and the diameter of the measurement section. In the case of an open measurement section, as it is in our case, this influence of the BE is very small. But anyhow it can influence the measurement value of the DUT. Thus a measurement uncertainty due to this effect is added to the whole uncertainty budget.

The wind tunnel consists amongst others of a ventilation system for setting the desired air velocity. Both the velocity and the temperature take some time for stabilization which is defined within the measurement program. If the response time of the DUT is larger than the stabilization time one has to take care that the DUT provides stable values before the measurement is started. The measurement time depends on both the DUT and the whole system.

5 Measurements results and data evaluation

Two rounds of measurements have been performed, the first one in the summer of 2014 and the second one in the summer of 2015. A final group of measurements took place in the METAS' tow channel in May 2017.

5.1 First round results, 2014

METAS performed measurements with various reference instruments, while E+E only used the LDA as a reference.

5.1.1 MiniAir20 TS Results

The results for the vane anemometer MiniAir20 TS are summarised in Table 1 and represented graphically in Figure 4. METAS data taken with the 'Lambrecht' anemometer and the Pitot tube as reference instruments are denoted simply by the legend 'METAS' to differentiate it from the data where the METAS LDA has been used as reference. A small horizontal offset has been assigned to some points in Figure 4 for better readability, which does not affect the results.

	METAS						**E+E**	
	Lambrecht		Pitot		LDA		LDA	
Ref velocity (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)
0.5	0.01	0.04					0.005	0.010
1.0	0.01	0.04					0.005	0.012
2.0	-0.05	0.06			-0.07	0.02	0.004	0.013
3.0	-0.11	0.08			-0.10	0.02	0.019	0.018
5.0	-0.06	0.12			-0.05	0.04	0.044	0.027
10.0			0.04	0.47	0.12	0.08	0.110	0.051
15.0			0.22	0.33	0.24	0.12	0.155	0.074
20.0			0.34	0.29	0.28	0.16	0.198	0.098
25.0			0.24	0.28	0.30	0.20	0.242	0.121
30.0			0.14	0.33	0.32	0.24	0.288	0.145
35.0			0.05	0.40	0.31	0.28	0.324	0.169
40.0			0.02	0.43	0.43	0.32	0.360	0.194

Table 1: Deviation as a function of reference velocity for the MiniAir20 TS.

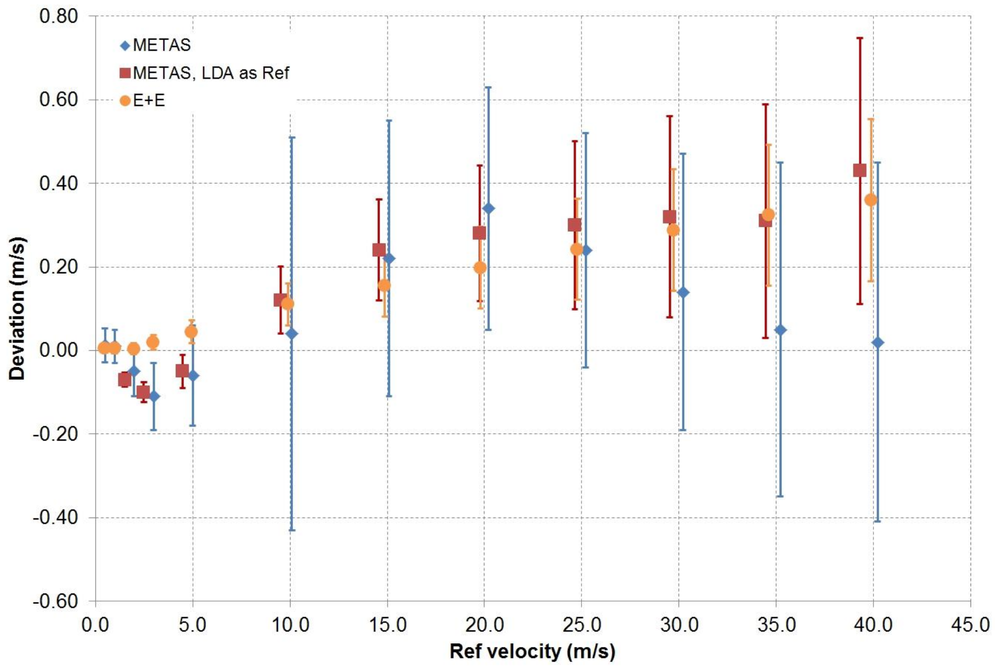


Figure 4: Deviation as a function of reference velocity for the MiniAir20 TS.

One immediately sees that the results obtained with the LDAs as references in both laboratories are in good agreement in the range (10 - 40) m/s. For the velocity range below 10 m/s, the results from METAS using 2 different references are consistent and show the same trend in deviation while the E+E results are in clear disagreement and present a different trend.
Based on the results presented above, EN factors have been calculated and are presented graphically in Figure 5. As expected, results below 10 m/s are not in good agreement. Further investigations are needed.

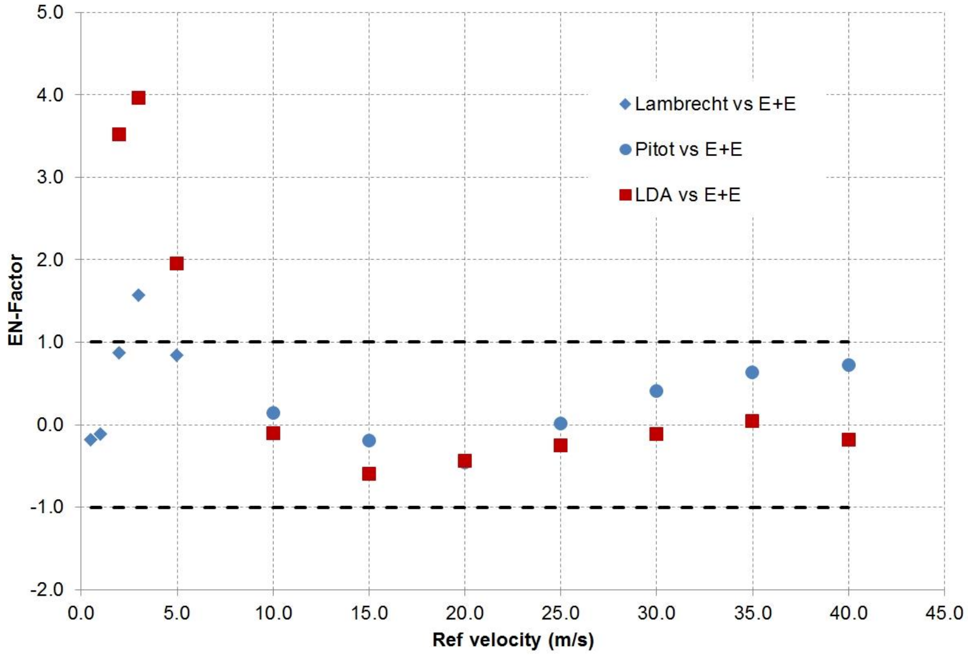


Figure 5: EN-Factor as a function of reference velocity for the MiniAir20 TS for the various reference instruments.

5.1.2 ManoAir500 TS Results

The results for the Pitot tube MiniAir20 TS are summarised in Table 2 and represented graphically in Figure 4. As in the previous section, METAS data are labelled by the type of reference instrument used: Lambrecht, Pitot or LDA. Again, a small horizontal offset has been added for a better readability of Figure 6.

	METAS						**E+E**	
	Lambrecht		Pitot		LDA		LDA	
Ref velocity (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)
0.5							0.006	0.058
1.0	0.55	0.02					-0.024	0.058
2.0	0.32	0.04	0.6	0.15	0.36	0.02	0.018	0.059
3.0							-0.011	0.061
5.0	0.12	0.18	0.13	0.18	0.12	0.04	-0.016	0.064
10.0	0.00	0.30	0.11	0.30	-0.03	0.08	-0.017	0.077
15.0	-0.01	0.32	0.06	0.32	-0.13	0.12	0.014	0.094
20.0			0.01	0.27	-0.18	0.16	0.051	0.116
25.0			0.08	0.26	0.06	0.20	0.069	0.138
30.0			0.03	0.31	-0.02	0.24	0.111	0.168
35.0			0.10	0.36	0.12	0.28	0.167	0.192
40.0			0.25	0.41	0.25	0.32	0.245	0.214

Table 2: Deviation as a function of reference velocity for the ManoAir500 TS.

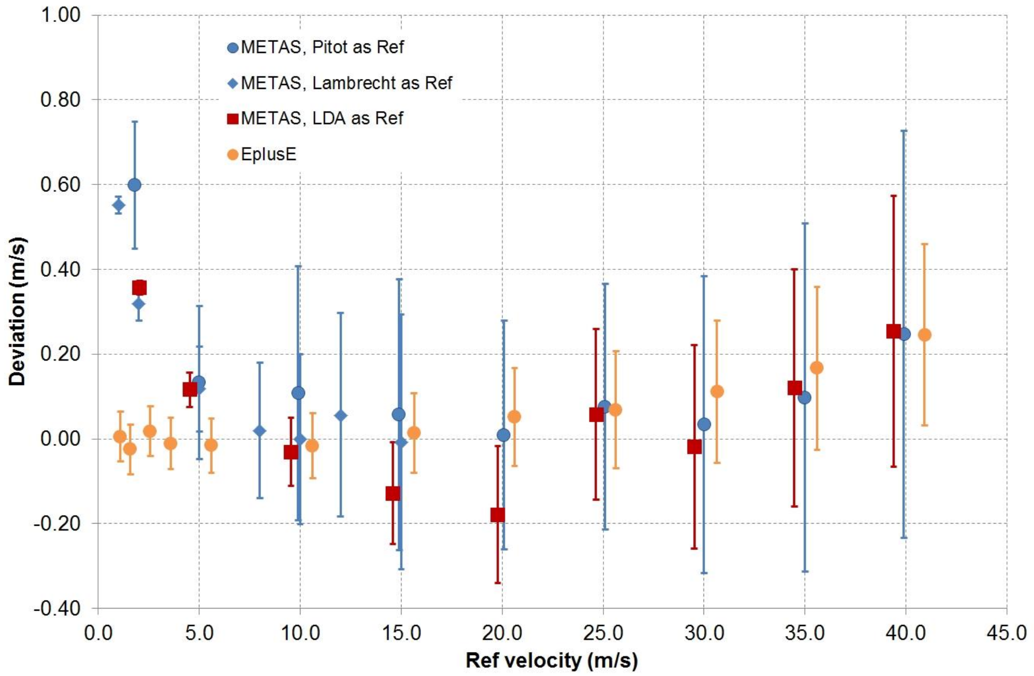


Figure 6: Deviation as a function of reference velocity for the ManoAir500 TS.

One sees that the agreement above 5 m/s between the two laboratories is good for results obtained with the METAS Pitot tube. The METAS LDA data show outliers at 15 m/s and 20 m/s. For velocities below 10 m/s, agreement is poor between the laboratories, although METAS data measured with different reference instruments are consistent.

Based on these results presented above, EN factors have been calculated and are presented graphically in Figure 7. A good agreement is observed above 5 m/s for data obtained with the METAS Pitot tube. LDA data shows reasonable agreement. Results below 10 m/s are not consistent. This could be due to the fact that no zeroing of the pressure meter has been performed by METAS between measurements, which could lead to an offset in the pressure data needed to determine the air velocity.

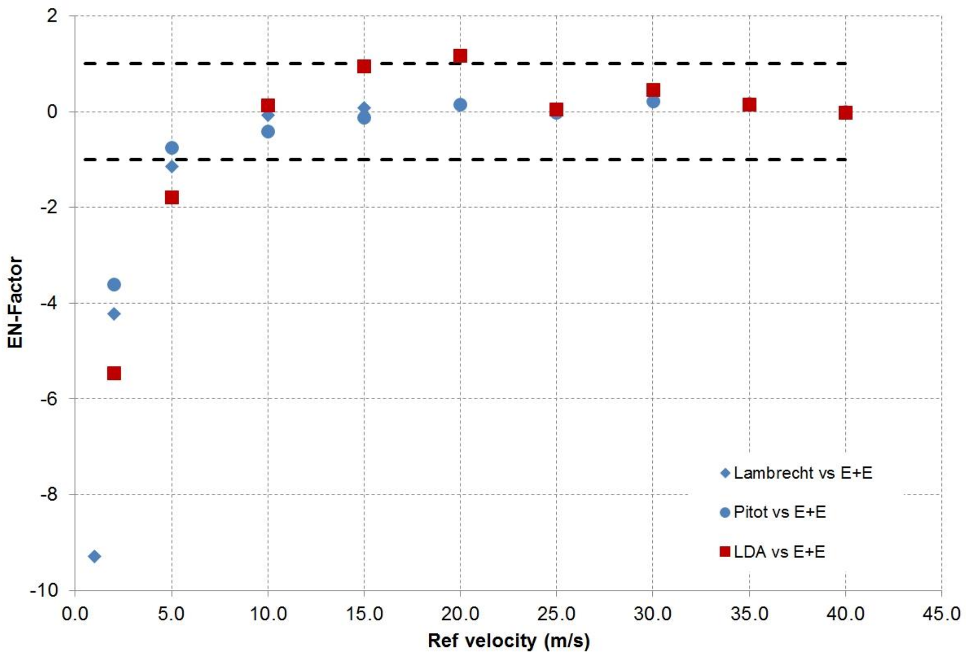


Figure 7: EN-Factor as a function of reference velocity for the MiniAir20 TS for the various reference instruments.

5.2 Second round results, 2015

Based on the results presented in the previous sections, it was decided to go through a second round to perform further investigations, namely the range below 10 m/s for the vane anemometer MiniAir20 TS and the intermediate velocity region for the Manoair500 TS, where the METAS LDA showed outliers.

5.2.1 MiniAir20 TS Results

The results in 2014 for this TS showed consistent results between both laboratories for velocities above 5 m/s. A new round of measurements in the velocity range below 10 m/s has been organised. The results from this campaign are shown in Figure 8, together with data from the previous round. Full and open symbols denote data from 2015 and 2014, respectively.

	METAS				E+E	
	Lambrecht		LDA		LDA	
Ref velocity (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)
0.5	0.01	0.04	-0.02	0.02	-0.05	0.01
1.0	0.00	0.04	-0.02	0.02	-0.05	0.01
1.5	-0.03	0.05	-0.06	0.02	-0.08	0.01
2.0	-0.05	0.05	-0.08	0.02	-0.11	0.02
2.5	-0.09	0.07	-0.11	0.03	-0.14	0.02
3.0	-0.10	0.17	-0.13	0.03	-0.17	0.02
3.5	-0.10	0.17	-0.13	0.04	-0.17	0.03
4.0	-0.08	0.10	-0.13	0.04	-0.17	0.03
4.5	-0.07	0.07	-0.11	0.05	-0.17	0.03
5.0	-0.06	0.07	-0.11	0.05	-0.16	0.03
8.0	0.01	0.10	-0.03	0.08	-0.13	0.04
10.0	0.07	0.13	-0.01	0.10	-0.09	0.05

Table 3: Deviation as a function of reference velocity for the MiniAir20 TS, 2015 data.

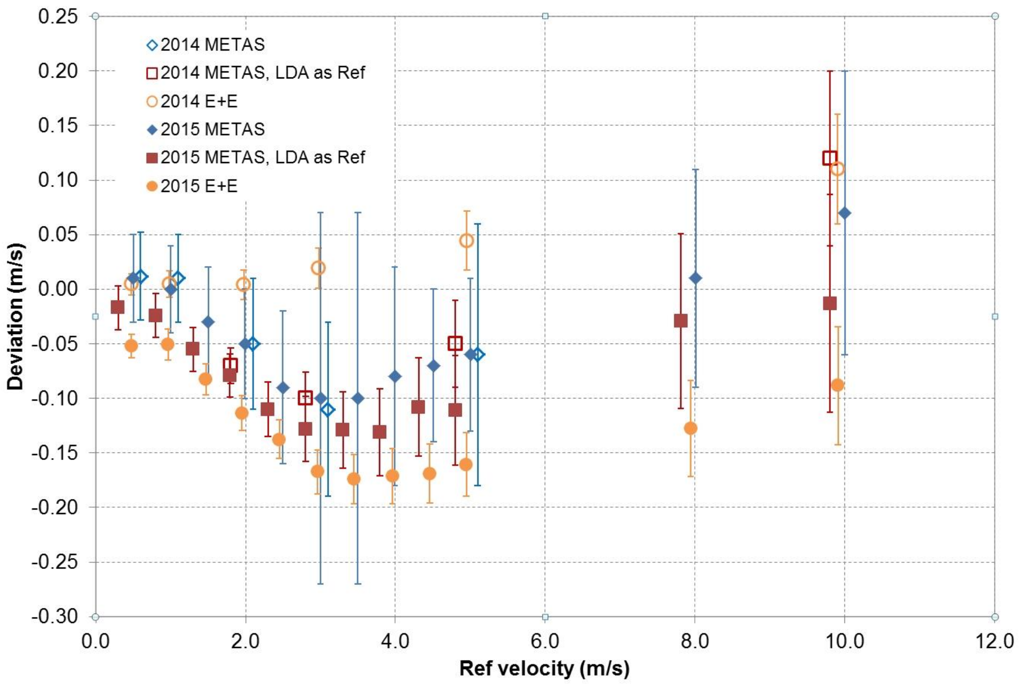


Figure 8: Deviation as a function of reference velocity for the MiniAir20 TS.

One sees that E+E data from 2014 and 2015 are not consistent, while METAS data, using different reference instruments, is. E+E data from 2015 follows a similar trend than the METAS data, however with an offset.

Reproducibility of the TS has been investigated by METAS by performing several measurements on different days in the range (0.5 – 3.0) m/s and yields a maximum contribution from 0.008 m/s (k=2) based on a rectangular distribution. This does not account for the observed deviation.

At E+E two types of corrections are applied to the measurement results. First the Blockage-correction due to the influence of the DUT on the profile and second the position correction due to the difference of the LDA measurement position and the calibration.

The Blockage-factor is determined from the modification of the profile because of the presence of the DUT. An LDA position is selected where the influence is a minimum and the remaining influence is added to the uncertainty budget.

The position correction factors are determined by the ratio of the measured velocity at the position of the DUT without a DUT and the LDA measurement position. These measurements are performed with the LDA prior to the calibration.

The measurement results from 2014 come from three sequential measurements that could not be reproduced. It is possible that there was a problem during zeroing the DUT. The measurements from 2015 could be reproduced several times and even after remounting the DUT. Thus it is recommended to skip the data from 2014.

5.2.2 ManoAir500 TS Results

The results in 2014 for this TS showed consistent results between laboratories for velocities above 5 m/s and only for one type of METAS reference. A new round of measurements has been organised for confirmation. The 2014 and 2015 results for this TS are shown in Figure 9, together with data from the previous round. Full and open symbols denote data from 2015 and 2014, respectively.

	METAS				E+E	
	Pitot		LDA		LDA	
Ref velocity (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)
0.5					0.16	0.10
1.0					0.10	0.05
2.0					0.04	0.03
3.0					0.05	0.02
5.0	-0.03	0.20	-0.04	0.05	0.01	0.03
8.0	-0.03	0.20	-0.05	0.08		
10.0	-0.01	0.30	-0.02	0.10	-0.04	0.05
12.0	-0.05	0.30	-0.07	0.12		
15.0	-0.01	0.40	-0.01	0.15	-0.03	0.08
20.0	0.04	0.40			-0.02	0.10
25.0	0.08	0.40			0.00	0.12
30.0	0.15	0.40			0.06	0.15
35.0	0.20	0.50			0.09	0.17
40.0	0.27	0.50			0.17	0.19

Table 4: Deviation as a function of reference velocity for the ManoAir500 TS, 2015 data

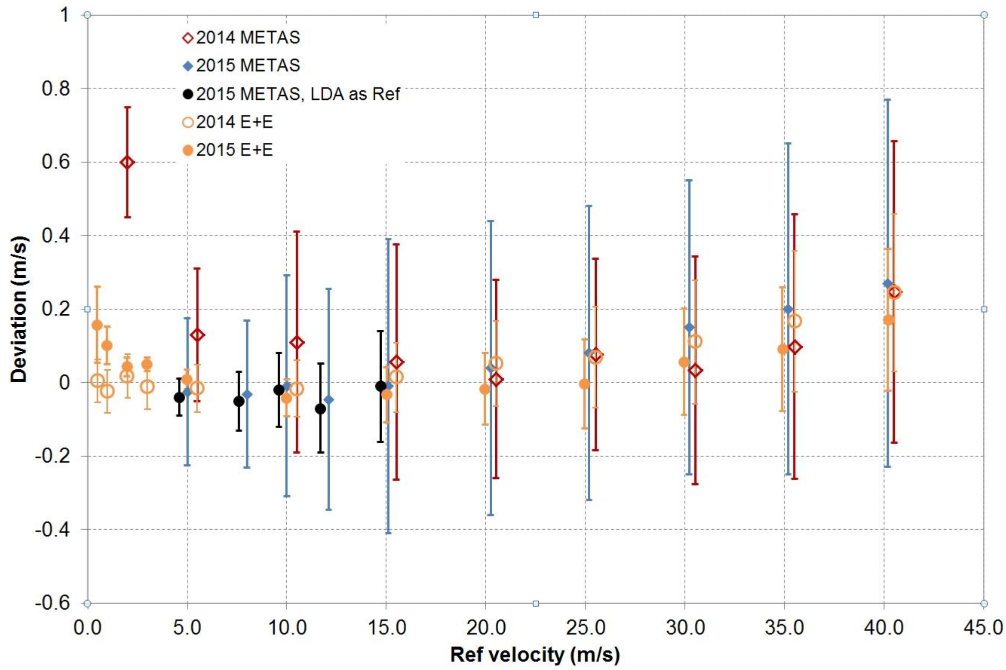


Figure 9: Deviation as a function of reference velocity for the ManoAir500 TS

One sees that E+E data from both rounds are consistent, except for the 2 lowest velocities. There is a good agreement between both laboratories. The METAS LDA outlier observed in 2014 at 15 m/s is no longer visible. This could be traced back to a defect on one of the channels of the ADC card used to acquire the light intensity signal from the LDA which happened only for a specific range of sampling frequency and introduced a shift in the calculated frequency spectrum. This has been checked by applying a fixed frequency signal to the ADC card input using a frequency generator and comparing its frequency to the calculated frequency from the sampled data. The second channel of this ADC card has been used during the 2015 data taking period and explains the better agreement. Unfortunately, METAS data with the LDA as reference only goes up to 15 m/s.

5.3 MiniAir20 TS METAS tow channel Results

To further investigate the observed deviation between METAS and E+E results below 6 m/s, further measurements were performed in the METAS tow channel, as in this case, blocking effects should be negligible. The METAS tow channel results are presented in Table 5 and graphically in Figure 10, together with METAS and E+E data taken in 2015.

	METAS						E+E	
	Lambrecht		LDA		Tow channel		LDA	
Ref velocity (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)	Deviation (m/s)	U (m/s)
0.5	0.01	0.04	-0.02	0.02	-0.0074	0.0115	-0.05	0.01
1.0	0.00	0.04	-0.02	0.02	-0.005	0.013	-0.05	0.01
1.5	-0.03	0.05	-0.06	0.02			-0.08	0.01
2.0	-0.05	0.05	-0.08	0.02	-0.121	0.016	-0.11	0.02
2.5	-0.09	0.07	-0.11	0.03			-0.14	0.02
3.0	-0.10	0.17	-0.13	0.03	-0.185	0.019	-0.17	0.02
3.5	-0.10	0.17	-0.13	0.04			-0.17	0.03
4.0	-0.08	0.10	-0.13	0.04			-0.17	0.03
4.5	-0.07	0.07	-0.11	0.05			-0.17	0.03
5.0	-0.06	0.07	-0.11	0.05	-0.150	0.025	-0.16	0.03
8.0	0.01	0.10	-0.03	0.08			-0.13	0.04
10.0	0.07	0.13	-0.01	0.10			-0.09	0.05

Table 5: Deviation as a function of reference velocity for the MiniAir20 TS, 2015 and 2017 tow channel data

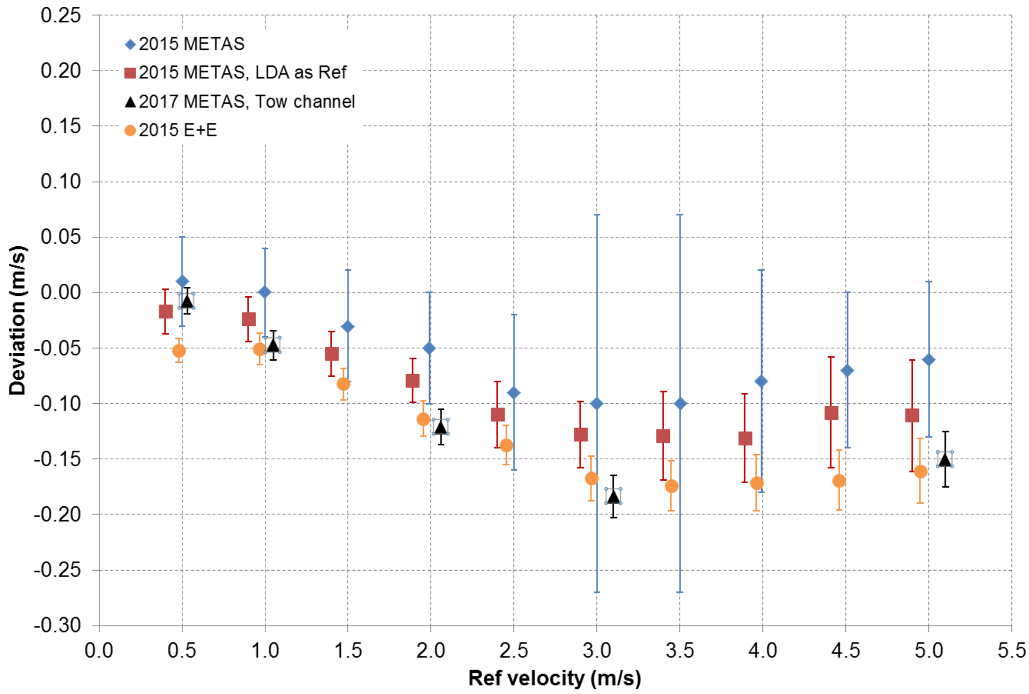


Figure 10: Deviation as a function of reference velocity for the MiniAir20 TS, 2015 and 2017 tow channel data.

One clearly sees a very good agreement between METAS tow channel and E+E data, except at the lowest velocity of 0.5 m/s. This implies that the blocking effect correction as implemented by E+E for this TS is correct and that, even given METAS' wind tunnel relatively large dimensions, some correction for blocking is needed for such TS.

6 Conclusions

The aim of this pilot study between the Austrian DI for airspeed and the Swiss NMI METAS was to assess the effect of wind tunnel cross section and calibration methods on the calibration results for two transfer standards with notable different apparent surfaces over a speed range from 0.5 m/s to 40 m/s:

- a Pitot tube with a diameter of 8 mm and
- a vane anemometer with a diameter of 85 mm.

A good agreement has been observed between both laboratories for data taken with the Pitot tube, which has a small apparent cross section compared to the wind tunnels cross sections. METAS and E+E presented consistent data for the speed range 5 m/s to 40 m/s.
The data taken with the vane anemometer, which had a much larger cross section than the Pitot tube, show that special care has to be taken during measurements and that one needs to determine the influence of the DUT on the flow profile. This results in a correction factor that depends on position and air velocity.
The interesting outcome of this pilot study is the fact that it is possible, by taking blocking effects into account, to calibrate, with an LDA vane anemometers with a large cross section ratio with respect to the wind tunnel. This has been proved by comparing data measured and corrected for blockage effect in the E+E wind tunnel, which has a relatively small cross section, to data obtained using METAS' tow channel, where blocking effect should be neglected due to the very large cross section of the facility. It could also be shown that even given METAS' wind tunnel relatively large cross section, some blocking effect is still present. It is more pronounced, as one may intuitively guess, when the reference instrument is the 'Lambrecht' vane anemometer due to its large size. This will have to be investigated by further measurements with the METAS wind tunnel.
It should be noted that a new Euramet project has been started in 2017 under the coordination of CMI to address blocking effects in wind tunnels.